Human Spaceflight Trajectory Operations: A case study from STS-132/ULF4

Flight Operations Virtual Forum
61st International Astronautical Congress

NASA JSC/Rebecca Cutri-Kohart
NASA JSC/Ansley Browns

30 Sept 2010

Overview

- ISS and Space Shuttle Trajectory Operations
- The challenge: A post-docking conjunction
- Space Shuttle rendezvous profile
- The solution as flown for STS-132
- Best practices and lessons learned

Mission Control Center Trajectory Operations

- Both ISS and Space Shuttle have their own Mission Control teams responsible for the operations of their vehicles.
- Space Shuttle Flight Dynamics Officer ("FDO")
  - Responsible for the trajectory of the Space Shuttle including:
    - Orbit determination
    - Ephemeris modelling
    - Maneuver targeting (orbit insertion, rendezvous, and deorbit)
    - Contingency planning
    - Conjunction evaluation
  - Supported by a team of navigators and trajectory phase specialists
- ISS Trajectory Operations and Planning Officer ("TOPO")
  - Responsible for the trajectory of the ISS including:
    - Orbit determination
    - Ephemeris modelling
    - Maneuver planning (reboost)
    - Conjunction evaluation
    - Contingency planning

Conjunction Operations

- Both TOPO and FDO work with the Department of Defense (DoD)Joint Space Operations Center (JSpOC) to identify potential conjunctions between the ISS or Shuttle and space debris
- Process:
  - The trajectory(actual and predicted) for the Shuttle is provided to the DoD
    - The DoD uses their own tracking of the ISS
  - If an object is within a certain distance of the Shuttle or ISS, the DoD notifies the FDO/TOPO and provides data for the object
  - The FDO/TOPO will determine the risk of collision with the object
    - Risk can be dependent on uncertainty of the future trajectory due to perturbations and maneuvers planned
  - If the risk exceeds a certain threshold (“red” or “yellow”), a collision avoidance maneuver will be considered
    - If risk is below that threshold (“green”), no action will be taken

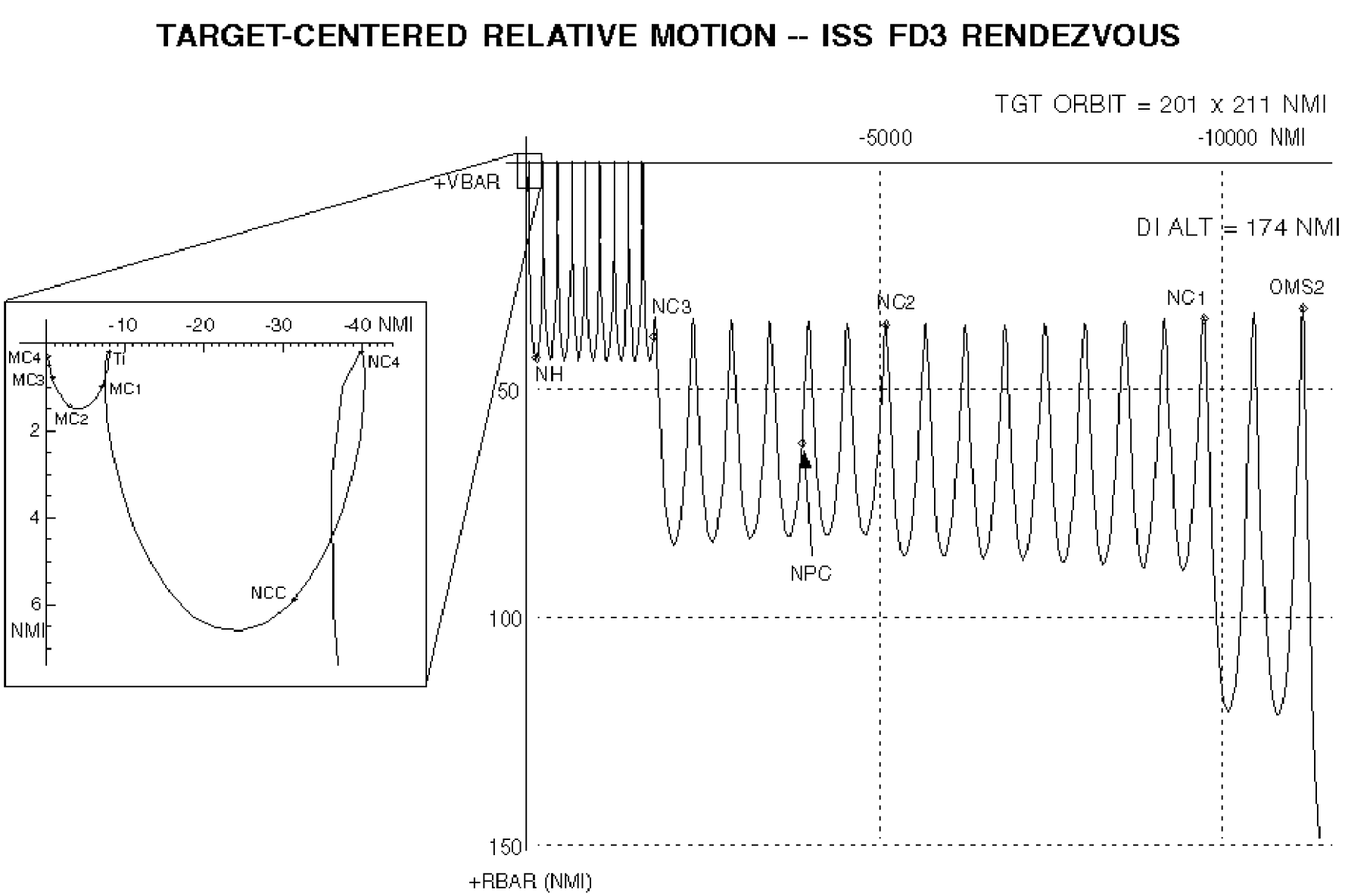
The Challenge: A conjunction with the ISS

- STS-132 Launch Minus 1 Day
  - The TOPO receives notification of a space debris conjunction with the ISS
  - The Time of Closest Approach (TCA) is ~1 hr after planned Space Shuttle docking
  - Early calculations show this conjunction is potentially “red” or “yellow”
    - The ISS may need to maneuver to keep a safe distance
    - The Space Shuttle launch is targeted based on rendezvousing with ISS in a predicted position
    - If the ISS does not maneuver, the Space Shuttle is also at risk since it will be docked to the ISS at the TCA
    - With 3 days to the TCA, lots of uncertainty
- Question: Does the Shuttle launch window or rendezvous plan need to be altered to accommodate a potential ISS collision avoidance maneuver?
- Operational challenge:
  - TOPO team needs to determine magnitude of maneuver that will create safe separation from debris (involves coordination with Russian trajectory team)
  - FDO team needs to determine if ISS maneuver impacts the rendezvous plan and advise on timeline issues

Space Shuttle / ISS Rendezvous Profile

- Phase angle
  - Defined as the angle between shuttle and ISS at orbit insertion
  - “Long Phase Angle” – The angle is large and the shuttle has to stay in a lower orbit than the ISS in the days before rendezvous in order to catch up.
  - “Short Phase Angle” – The angle is small and the shuttle is at nearly the ISS altitude in the days before rendezvous
  - Phase angle is launch day and time dependent
- Pre-Day of Rendezvous Ground Targeted Burns
  - NC-# - Phasing Burns - Performed in the morning and evening of crew day. These burns are targeted to place NC-4 at 40 nmi behind the ISS
- Day of Rendezvous Ground Targeted Burns
  - NH – Height Adjust – Only required on Long Phase Angle days to raise the orbit to just below ISS altitude
  - NC-4 – Phasing Burn #4 – Last ground targeted burn before the use of relative navigation sensors. Targets a Terminal Initiation (Ti) burn at 8 nmi behind the ISS

Space Shuttle / ISS Stable Orbit Rendezvous



STS-132 / ULF4 Rendezvous

- Long phase angle with a large Day of Rendezvous NH
- NC-3 on Flight Day 2 was the last opportunity to set up phasing rate to arrive NC-4 at 40 nmi behind ISS
  - Normally the ISS decision point for a go/no go for a collision avoidance maneuver would have occurred after NC-3. Coordination between the two teams moved the decision point to prior to NC-3
  - This allows two different NC-3 burn plans for two different ISS positions depending on go/no go for collision avoidance maneuver
  - Day of Rendezvous NH also gives you flexibility to adjust phasing.
    - In this case, even if NC-3 had been adjusted for one option, and decision changed, NH could have been altered

STS-132/ULF4 Rendezvous: “What If”

- What if it had been a short phase angle launch day?
  - No NH means Day of Rendezvous set up entirely by NC-3
  - Small perturbations in the ISS trajectory or Shuttle trajectory after NC-3 can result in ~20 nmi in dispersion of NC-4 position
    - A large perturbation like a collision avoidance burn could make an even larger difference resulting in significant extra propellant use or even delayed rendezvous
  - May not have been enough to make the decision prior to NC-3, but it may have been necessary to perform the burn and get post-burn tracking on the ISS before targeting NC-3
- Conclusion: Earlier decision points are required if you have a less flexible rendezvous plan
  - Could even require re-targeting launch time

Lessons Learned and Best Practices

- Team coordination
  - ISS/TOPO team is able to send burn plan and post-burn ISS state to Shuttle/FDO team using a common tool set that allows easy evaluation
  - Neither team could work to an independent timeline because they were tied to the other team's decision points
  - "Two cooks in the kitchen" – since the conjunction was after docking, it was a potential risk to both vehicles, so both teams had to agree on a criteria for assessing risk, even though only one vehicle had to maneuver
- Strengths of Shuttle rendezvous profile
  - Burn targets need only be provided 30 minutes prior to a maneuver
    - This allows real time teams to continuously evaluate changes to the plan until the last minute
  - Long phase angle rendezvous profiles have NH
    - This allows team to adjust day of rendezvous profile as late as possible after all other trajectory events are complete
- What happened?
  - Updated tracking on Flight Day 2 showed a reduced threat from the object and just before NC-3 the team decided to call off the ISS collision avoidance burn

Questions

Bibliography

Flight Dynamics Officer Console Handbook Volume 3 (Rev A, PCN 9-3) (2010) NASA Johnson Space Center

Goodman, John L. (2006). "History of Space Shuttle Rendezvous and Proximity Operations." *Journal of Spacecraft and Rockets*, Vol 43, No 5, pp 944-959.

Malik, Turiq (2010, May 15). "Space Junk May Make Shuttle's Arrival at Station Trickier," from http://www.space.com/missionlaunches/space-junk-shuttle-atlantis-station-100515.htmlpa

"Space debris and human spacecraft." Retrieved from http://www.nasa.gov/mission_pages/station/news/orbital_debris.html on Aug 12,2010.

All photos retrieved from http://spaceflight.nasa.gov multimedia gallery.